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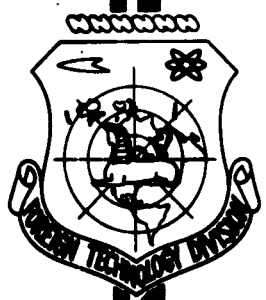
INCREASING THE RATE OF COMBUSTION
BY INTRODUCING AN INERT ADMIXTURE

BY

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INCREASING THE RATE OF COMBUSTION BY INTRODUCING AN INERT ADMIXTURE

by

N. N. Bakhman

(Presented by the Academician V. N. Kondrat'yev, February 10, 1962)

1. Let us consider a system in which the combustion proceeds in a kinetic mode of operation, but the heat emission is concentrated in one narrow zone. For the rate of combustion of such systems the following expression ⁽¹⁾ will be valid

$$m \sim \sqrt{\frac{\lambda \Phi_{\max}}{q^2} \frac{RT_{\max}^2}{E}} \quad (1)$$

where m (g/cm² · sec) is the mass rate of combustion; Φ_{\max} (cal/cm³ · sec) is the rate of the volumetric heat emission at $T = T_{\max}$; q (cal/g) is the heat of the reaction.

From (1) it follows that in steady equal conditions the mass rate of combustion increases with the reduction in the heat of the combustion. The sense of this result proves to be trivial if q changes exclusively on account of the introduction of an inert admixture, i. e., an admixture which does not react with the original system and does not have a catalytic action. It is unnecessary, furthermore, to remark that at least in the case of the addition of solid particles, there probably do not exist completely inert admixtures. In this sense the concept of inert admixture proves to be only a limit case to which the real admixtures may only to some degree or other be approximated.

Let us mark with a prime the values relating to the system with inert admixture. For the heat of the combustion per gram of mixture with admixture one may write

$$q' = (1 - \xi) q_0 \quad (2)$$

where ξ is the weight fraction of the admixture and $q_0 = \text{const}$ is the heat of the combustion of the active (unadulterated) substance. The rate of the emission of heat in a unit of volume of the flow we will write in the form

$$\Phi_{\text{maxc}} = q_0 \frac{\kappa_{\text{акт}}}{\Gamma_{\text{акт}}} \cdot \omega'_{\text{maxc}} \frac{\Gamma_{\text{акт}}}{\text{см}^3 \cdot \text{сек}} \quad (3)$$

where q_0 and ω'_{maxc} are taken per gram of active substance.

By disregarding κ and E we get from (1) — (3):

$$m' \sim \frac{1}{1-\xi} \sqrt{\frac{\lambda \omega'_{\text{maxc}} R (T'_{\text{maxc}})^2}{q_0 E}} \quad (4)$$

In (4), the increase in m' in proportion to the decrease in the heat of combustion is described by the multiplier $1/(-\xi)$ which gives the top limit of the possible increase of m' for account of the introduction of an inert admixture (thus, with $\xi = 0.15$ m' at the limit can increase by 1.175 times, at $\xi = 0.30$ by 1.43 times, etc.).

Having divided m' from (4) by m , where m relates to the initial system

$$(\xi = 0, \lambda = q_0) \text{ we will get } \frac{m'}{m} \sim \frac{1}{1-\xi} \frac{T'_{\text{maxc}}}{T_{\text{maxc}}} \sqrt{\frac{\omega'_{\text{maxc}}}{\omega_{\text{maxc}}}} \quad (5)$$

Here with the increase in ξ the multiplier $1/(1-\xi)$ has an effect in the direction of increasing m'/m , while the lowering of $T'_{\text{maxc}}/T_{\text{maxc}}$ and $\omega'_{\text{maxc}}/\omega_{\text{maxc}}$ influences in the direction of decreasing m'/m . The resulting value of m'/m in the case of introducing an inert admixture can be smaller or greater than unity but not greater than $1/(1-\xi)$. The sense of the multiplier $1/(1-\xi)$ in the right side of (4) and (5) becomes clear if one presents m' in the form of the sum of the flow of the unadulterated substance and the flow of the inert admixture:

$$m' = m'_{\text{акт}} + m'_{\text{ин}} = (1-\xi) m' + \xi m'. \quad (6)$$

For mass rate of combustion computed per gram of unadulterated substance we obtain

$$m'_{\text{акт}} = (1-\xi) m' \sim \sqrt{\frac{\lambda \omega'_{\text{maxc}} R (T'_{\text{maxc}})^2}{q_0 E}} \quad (7)$$

i. e., $m'_{\text{акт}}$ can only decrease with the increase in ξ , but $m'_{\text{акт}}/m$ is always less than unity. In this way the member $1/(1-\xi)$ represents an increase in the mass flow for account of mixing in of mass of the inert substance.

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2. The form of the multiplier $w_{\text{maxc}}'/w_{\text{maxc}}$ on the right side of (5) depends on whether the inert admixture consists of gas or solid particles. We will be interested only in the latter case. In this case the partial pressure of the active gas is equal to the full pressure, but part of the volume of the flow V'_q is occupied by particles. Hence

$$\frac{w_{\text{maxc}}'}{w_{\text{maxc}}} = (1 - V'_q)^n \exp \left[\frac{E}{R} \left(\frac{1}{T_{\text{maxc}}} - \frac{1}{T_{\text{maxc}}'} \right) \right] \left(\frac{T_{\text{maxc}}}{T_{\text{maxc}}'} \right)^n$$

where ordinarily $1 - V'_q \simeq 1$.

In the case of admixture of solid particles with little heat capacity (especially such as Ta, W, Re, etc.) it is very easy to go very close to the limit value

$$\left(\frac{m'}{m} \right)_{\text{max}} = \frac{1}{1 - \xi} \gg 1. \quad (9)$$

Naturally, the given particles (as, indeed, the most solid particles) in the experiment can turn out to be not completely inert with relation to the system selected. In this case the experimental value of m'/m will be determined by the joint influence of dilution, catalytic effect of the particles (positive or negative) and the reaction of the particles with the initial system. Correspondingly the experimental value of m'/m does not have to be close to $1/(1 - \xi)$.

3. It is of interest also to consider the relationship of the linear

	Initial system without particles		System with admixture of particles	
	condensed phase (k- phase)	gas phase	k- phase	two-phase flow
Density of gasified components	P	P_{gas}	P	P_{gas}
Density of particles	—	—	P_q	P_q
Average density	P	P_{gas}	P_{cp}	$P_{\text{cp}} (q_0)$
Linear rate of combustion	u	u	u'	u'
Volumetric share particles	—	—	V_q	V_q
Share of area of transverse section occupied by particles	—	—	S_q	S_q

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rates of combustion (relative to the condensed phase) for the case where the solid particles adulterate the condensed system components of which are then gasified (before the beginning of the reaction).

Let us introduce the symbols shown at the bottom of the preceding page.

For brevity we consider the case only of quite small particles the speed and temperature of which in any section of the flow are equal to the speed and temperature of the gas. In this case one may write

$$V_s = S_s = S_g \frac{u'}{u}, \quad (10)$$

where ordinarily $u' \ll u$ and correspondingly $V_s = S_s \ll 1$. For fine particles their weight share in the k-phase and in the two-phase flow is the same. Besides, we will make use of the relationships (valid for particles of any size):

$$\frac{1}{\rho_{cp}} = \frac{\xi}{\rho_s} + \frac{1-\xi}{\rho}, \quad (11)$$

$$V_s = S_s = \frac{\xi \rho_{cp}}{\rho_g}. \quad (12)$$

Having determined the mass rate of the combustion as $m' = \rho_{cp} u'$ and $m = \rho u$ we will get for the ratio of the linear rates of combustion of the system with admixture of solid particles and without admixture the following expression:
$$\frac{u'}{u} = \frac{m'}{m} \frac{\rho}{\rho_{cp}} = \left(1 + \frac{\xi}{1-\xi} \frac{\rho}{\rho_g}\right) (1 - V_s)^{n/2} \left(\frac{T_{max}}{T_{maxc}}\right)^{1-n/2} \exp\left[\frac{E}{2R} \left(\frac{1}{T_{maxc}} - \frac{1}{T_{max}}\right)\right]. \quad (13)$$

In this expression the first multiplier $A = 1 + \frac{\xi}{1-\xi} \frac{\rho}{\rho_g}$, which increases together with ξ gives the top limit for u'/u . In this case A can change formally within arbitrarily wide limits through the change in ρ/ρ_g . However, computation shows that the value u'/u for the completely inert particles ordinarily turns out to be less than unity and only in rare cases slightly exceed it.

The presence of the multiplier $A = 1 + \frac{\xi}{1-\xi} \frac{\rho}{\rho_g}$ in (13) is connected with the specific two-phase flow. Actually, if for the single-phase flow (system without particles) the preservation of the flow of the

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mass is written in the form

$$\rho u = \rho_{\text{gas}} u, \quad (14)$$

then for the two-phase flow (in the system with admixture of solid particles)

we have

$$\rho u' = \rho_{\text{gas}} u' \frac{1 - S_q'}{1 - S_q}. \quad (15)$$

If $v = v'$ then from (15), (14), (12) and (11) there follows:

$$\frac{u'}{u} = \frac{1 - S_q'}{1 - S_q} \approx \frac{1}{1 - S_q} = 1 + \frac{\xi}{1 - \xi} \frac{p}{p_q}, \quad (16)$$

i. e., with identical rate of combustion relative to the gas the ratio

u'/u would immediately equal A .

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The sense of the difference between (14) and (15) consists in the fact that in the k-phase fine particles occupy a greater part of the section than in the two-phase flow ($S_q \gg S_q'$), i. e., the gasification is accompanied by an expansion of the gas laterally. Correspondingly with $v' = v$ one should have $u' > u$.

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L i t e r a t u r e C i t e d

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